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All optical gain-clamped *L*-band EDFA using a ring resonator

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Abstract : All optical gain-clamped (GC) long wavelength band (*L*-band, 1570 ~ 1610 mm) erbium-doped fibre amplifier (EDFA) is demonstrated using a counter propagating ring resonator, in order to achieve constant gain with minimum gain variation. The clamped-gain level can be selected by controlling cavity loss using an optical attenuator or lasing wavelength in the clamping-loop using a tuneable bandpass filter. The optical gain of the amplifier decreased from 18.9 to 13.9 dB, and the corresponding noise figure degraded from 4.3 to 6.5 dB for the input 1580 nm signal power of −30 dBm when the clamping-loop attenuation of 1550 nm lasing wavelength is varied from 26.6 dB to 0 dB. Varying a lasing wavelength from 1565 to 1540 nm could also be used to control the clamped-gain level from 7 to 18 dB. However, the corresponding noise figure is degraded from 5.6 to 7.8 dB.

Keywords : Erbium doped fibre, optical amplifier, gain clamping.

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1. Introduction

The explosive growth of Internet traffic has placed severe demand on high capacity dense wavelength division multiplexing (DWDM) system with higher DWDM channel count. Recently, the so-called *L*-band EDFAs [1,2] with the extended gain region of 1570 ~ 1610 nm have emerged to satisfy the hunger of transmission bandwidth while in combination with conventional band (*C*-band) EDFA in a single optical fibre link. In DWDM networks, stabilising the channel gain constant of each EDFA in the presence of dynamic input power variation or add/drop of optical channels is very important to eliminate the power transient effects and to maintain satisfactory system performance of the surviving channels. The optical gain clamping technique has been extensively explored in *C*-band such as forming a feedback fibre loop or placing a fibre Bragg grating [3]. However, the gain clamping technique for *L*-band EDFA's has not been addressed.

In this communication, a design of the *L*-band gain-clamped EDFA using a counter propagating ring resonator is proposed and experimentally demonstrated. A portion of the *C*-band backward amplified spontaneous emission (ASE) is routed into the feedback loop at the input of the amplifier, filtered at a selected wavelength, attenuated and finally reinjected at the output end of the amplifier. The various lasing wavelength for optical gain clamping operation of the *L*-band GC-EDFAs in terms of different clamping loop attenuation are examined.

2. Experiment

Figure 1 depicts the configuration of the proposed *L*-band GC-EDFA, which includes a pair of optical circulators (OC1 and OC2), the conventional forward pumped *L*-band EDFA, an optical tuneable band-pass filter (TBF) and a variable optical attenuator (VOA). The conventional *L*-band EDFA is pumped by a laser diode at 980 nm with a maximum power at the fibre end of 98 mW. Pump and signal are coupled into a piece of erbium-doped fibre (EDF) through a wavelength selective coupler (WSC). A 50 m length of erbium-doped fibre with an ion concentration of 400 ppm, numerical aperture of 0.24 and cut-off wavelength of 962 nm is used as the active medium. A TBF with a bandwidth of 1.25 nm at 1550 nm is placed in the gain-clamping loop to filter the

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C-band backward ASE and determine the centre wavelength of lasing light. The direction of the lasing light is counter-clockwise, which is determined by both OC1 and OC2.

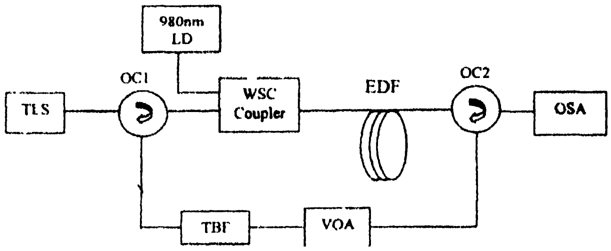

Figure 1. Configuration of L-band ring EDFA

The VOA is used to control the cavity loss in the clamping-loop. The output of the EDFA can be analysed from the output port of OC2 using an optical spectrum analyser (OSA).

3. Results and discussion

Figure 2 shows the gain and noise figure characteristics of the L-band GC-EDFA as a function of input signal power against various clamping-loop attenuations with the lasing wavelength fixed at 1550 nm. The input signal wavelength from tunable laser source (TLS) and pump power is fixed at 1580 nm and 98 mW, respectively. It is found that when the clamping-loop attenuation changes from 26.6 dB to 0 dB,

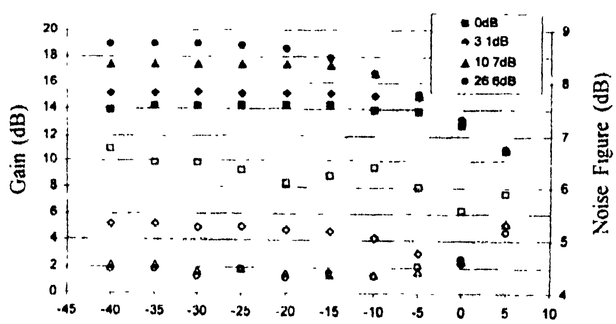

Figure 2. Gain (shaded) and noise figure (clear) as a function of input signal power at lasing wavelength of 1550 nm for various clamping-loop attenuation

the signal gain of the amplifier decreases from 18.9 to 13.9 dB and the corresponding noise figure degrades from 4.3 to 6.5 dB for the input power of −30 dBm. It is worthy to mention that when the clamping-loop attenuation decreases, the corresponding optical power of the lasing light increases. Such an increase induces the incomplete population inversion of EDF, and thus the inversion parameter $n_{sp} = N_2/(N_2 - N_1)$ increases, where N_2 is the population density of upper state and N_1 is the population density of lower state, and leading to the noise figure degradation. From Figure 2, the strongly clamped gain is 14.2 dB while the loop attenuation equal to 0 dB, corresponding to the strongest laser oscillating in the cavity, and the corresponding dynamic input power range is about 40 dB (from −40 to 0 dBm).

Figure 3 shows the optical gain and noise figure against various clamping-loop attenuations for input signal wavelength of 1580 nm and lasing wavelength of 1550 nm.

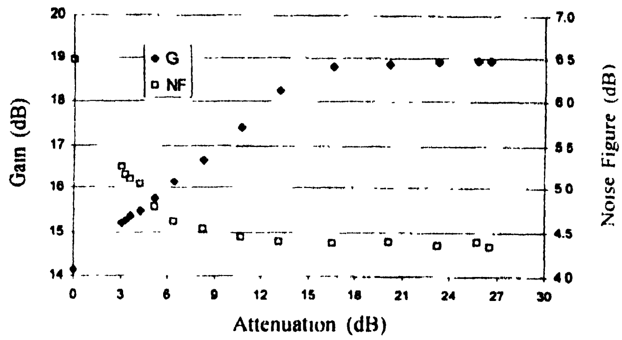

Figure 3. Gain and noise figure against various clamping-loop attenuations for input signal wavelength of 1580 nm and lasing wavelength of 1550 nm.

The input signal power and pump power is fixed at −30 dBm and 98 mW, respectively. By varying the clamping-loop attenuation from 0 to 16.5 dB, the clamped-gain is controlled from 14.2 to 18.9 dB. The gain is a monotonously increasing function of the attenuation from 0 to 16.5 dB. As for tuning efficiency, the clamped gain is varied for a different attenuation tuning with an allowable linearity of 0.28 dB/dB in average. We find that when the clamping-loop attenuation is above 16.5 dB, the optical gain becomes consistent at 18.9 dB and the corresponding noise figure is 4.4 dB. In this region, the cavity is operating below lasing threshold. Therefore, the condition for clamping effect is not satisfied. It is also worth mentioning that when the clamping-loop attenuation decreases from 16.5 dB, the gain-clamping effect enhanced but the noise figure degraded.

In Figure 4, the impact of varying the lasing wavelength is shown for clamping-loop attenuation of 0 dB. The input

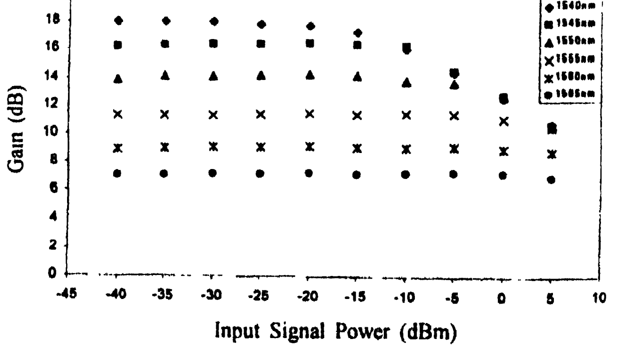

Figure 4. Gain as a function of input signal power for different lasing wavelength.

signal wavelength and pump is fixed at 1580 nm and 98 mW, respectively. The figure shows that the clamped-gain level is reduced with tuning the lasing wavelength nearer to the signal wavelength. The maximum gain is achieved with lasing wavelength of 1540 nm. Changing the lasing wavelength from 1565 to 1540 nm is able to control the clamped-gain level from 7 to 18 dB. However, the corresponding noise figure is degraded from 5.6 to 7.8 dB as shown in Figure 5. The lower clamped-gain causes the

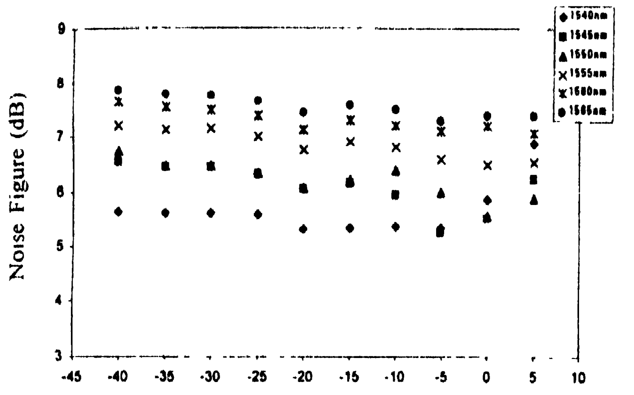

Figure 5. Noise figure as a function of input signal power for different lasing wavelength

population inversion to be clamped at a lower level and degrades the noise figure. Figure 5 also shows that the noise figure has a dip at high input signal power, especially for lasing wavelength of 1545 nm which gives a dip at –5 dBm input signal power. The dip is attributed to the interplay between self-saturation by backward amplified spontaneous emission (ASE) and self-induced saturation [4].

4. Conclusion

A gain-clamped *L*-band EDFA using a counter propagating ring resonator has been presented. The clamped-gain level and noise figure can be selected from 18.9 to 13.9 dB and from 18.0 dB to 7 dB, respectively, by controlling the lasing wavelength and clamping-loop attenuation. However, the noise figure is degraded with the maximum noise figure of 7.8 dB as the clamped-gain is decreased due to the lower level of population inversion. This *L*-band gain-clamped EDFA in combination with *C*-band gain-clamped EDFA in a parallel configuration may find important applications in DWDM broadband systems and networks to provide constant gain with minimum gain variation in the presence of dynamic input power variation and add/drop of optical channel.

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